Near-surface exploration for treasure-filled tunnels in grano-diorite

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SUMMARY

A seismic exploration program for shallow tunnels (-28 meter) in the Philippine province of Neuva Viscaya has identified target areas that correlate at several boreholes with the known location of subsurface voids.Two surveys were conducted: 3D VSP in the summer of 1995, and a fairly unconventional 3D geometry utilizing subsurface sources and surface geophonesin February of 1997. Analysis of both datasets by volumetric projection of anomalously low-amplitude raypaths confirmed the identification of a target zone at 28 meters. In March of 1997, miners directed by survey results working offshoots to a horizontal tunnel intersected a fracture zone at 28 meters depth. The target zone defined by the anomalously low-amplitude seismic data is co-located with this fracture.

INTRODUCTION AND HISTORICAL SYNOPSIS

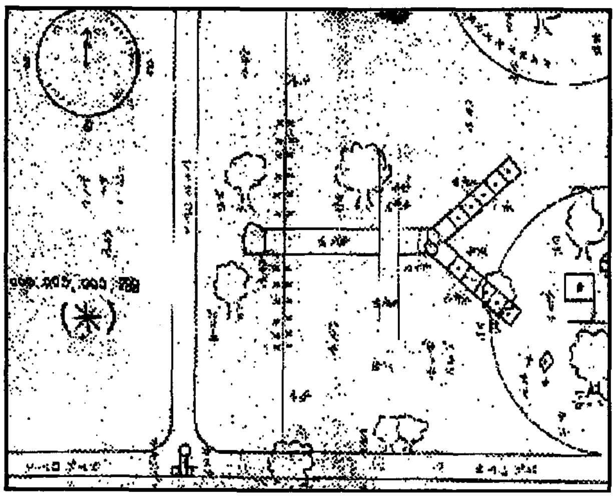


FIGURE 1: *Original Japanese Treasure Map of Tunnel-8.*

The field site has considerable historical significance. It was termed "Tunnel-8" during the Japanese occupation. During the war, the Japanese moved a great deal of treasure and valuable artifacts to the Philippines for inventory and storage prior to shipping to Japan Before these treasures could be safely relocated the Japanese Navy was destroyed. Understanding that they were facing defeat, the Japanese hid much of the treasure in tunnels on the island of Luzon. The Tunnel-8 site is believed to be one of the largest such Japanese treasure tunnels. The site was reportedly the destination of a large convoy of Japanese trucks transporting huge quantities of gold.

In 1945, Ben Balmores served as houseboy to Kimsu Marakusi. Kimsu was the director of treasure disposal in the Philippines and believed to be a member of Japanese Imperial household. He visited each treasure site with Ben Balmores at his side, and was provided with maps and detailed inventories. Near the end of the war they took a tour of all the treasure sites. At each site, the tunnels were typically dynamited shut, burying all the workers alive. Later, the surface was landscaped to cover all tracks

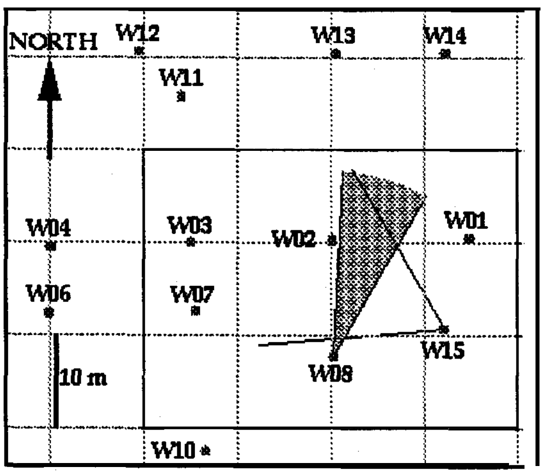


FIGURE 2: *Map View of Tunnel-8 site showing boreholes and location of target zone.*

General Yamashita, the supreme commander of Japanese forces in the Philippines, attended the Tunnel-8 'burial'. All others with first-hand knowledge of the treasure sites were reportedly in the Tunnel-8 complex as Ben, Kimsu, and Yamashita exited and the ground was shaken by a series of explosions. After the closing of Tunnel-8, Kimsu gave over 171 of the maps to Ben for safekeeping, extracting a promise that they wouldremain undisturbed until Kimsu's return

Many years later a high-ranking officer in the Philippine army learned of the maps in Ben's possession andforced bim to give up 171 of them.Ben had secreted away an additional 25 of what he considered the most important and valuable of the maps, and he later attempted to gain access to some of these sites. His attempts were. unsuccessful and he eventually quit due to poorhealth and lack of funds. Subsurface treasure sites of tbis magnitude typicallyrequire hundreds of thousands of dollars to explore. In 1988, Arch Ford began collaborating with Ben Balmores. Ford obtained several original Japanese treasure maps, including the map of Tunnel-8 shown in Figure. 1.

VSP SURVEY DESCRIPTION AND TARGET ZONE DELINEATION

In 1995, the first of two seismic surveys was conducted at the Tunnel-8 site, which is located under a well-saturated rice-paddy. Several deep boreholes (40 meters) were drilled and VSP and Crosswell surveys around and between the boreholes were collected using a 24-channel string of hydrophones. Figure 2 is a map view of the Tunnel-8 site showing the location of15 of the boreholes drilled up to the end of the 1995 survey. The black rectangle marks the bounds for 2D and 3D images that follow.

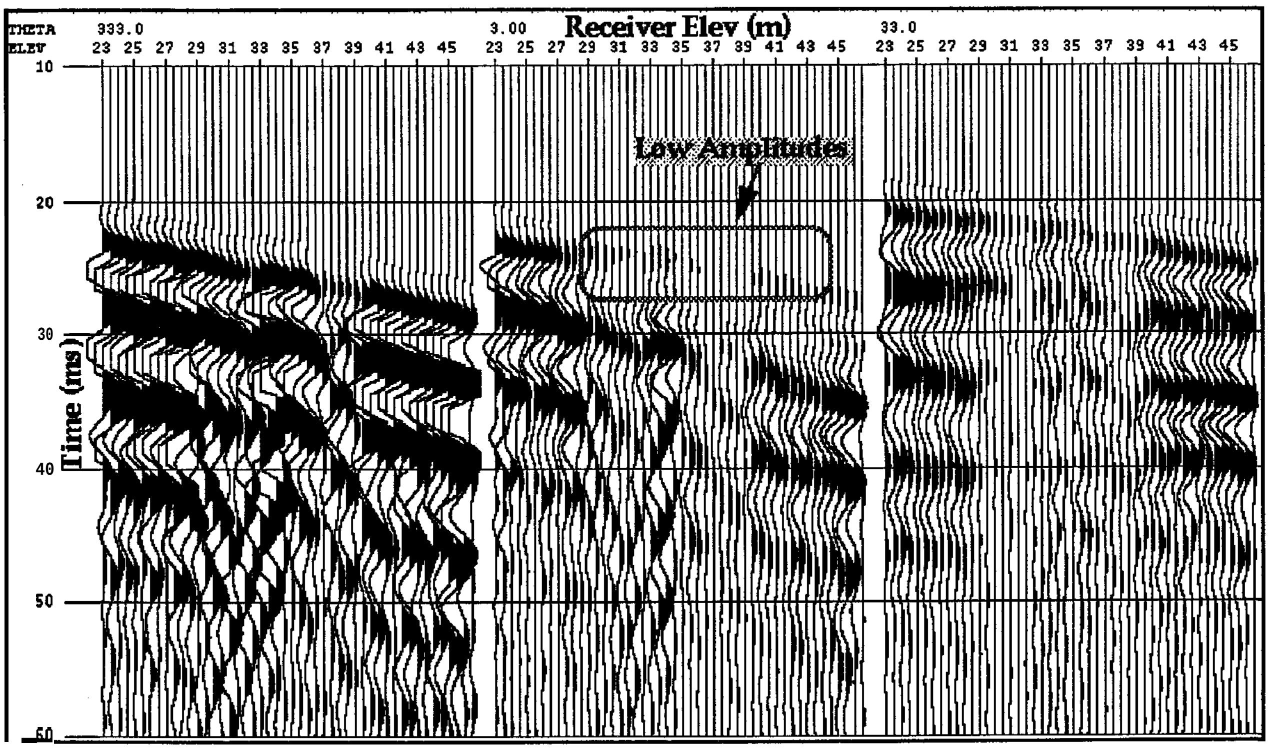
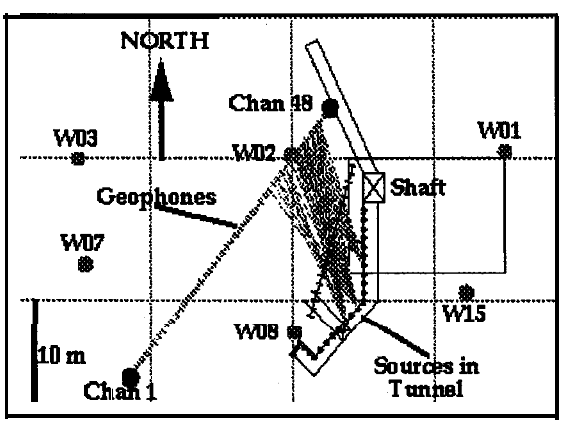


Figure 3: *Three common source gathers for VSP data in well 8, offset-20 meters, azimuth=333, 3, and 33 degrees. Notice the loss of amplitudes in the centerpanelfor all receivers below about 28 meters.*

Preliminary core analysis of from the boreholes indicated that below about 18 meters, the formation was very competent with very little fracturing. Consequently we expected that the presence of laterally varying features in the data below 18 meters would indicate man-made structure: e.g. the presence of the Japanese tunnel. Unfortunately, problems with the airgun source made the cmsswell data unusable. For the VSP, the recording geometry consisted of two offsets, 10 and 20 m., with azimuths sampled in 10-deg. increments. Figure 3 shows three VSP common source gathers (CSG's) from well 8. The data have been ensemble balanced from shot to shot, and statistically corrected for poorly coupled sources and receivers, but no other scaling has been applied. Note the decrease in ardval amplitude beginning at about 28 meters for theta=3 degrees. All data between azimuths theta=3 and theta=33 degrees, corresponding to the shaded pie section in Figure 2, exhibited a significant amplitude decrease. Given the remarkable coincidence between this depth and the proposed depth of the tunnel, we felt that we had detected a void or rubbleized zone associated with the tunnel.



This data was the primary factor determining the target zone shown in Figure 2. Siilarly, VSP data from well 15 identified an area at the same depth to the west. The data from tbis well was not as bigh quality, therefore the zone is delineated by solid lines only. Unfortunately, the boreholes were not cased, and many were clogged by debris and unusable for VSP. We were able to occupy 8 of the boreholes (1, 3 5, 8, 9, 10, 12, 14, and 15), but none of data from these wells displayed zones as anomalous as the one near wells 8 and 15.

1997 SURVEY DESCRIPTION

Based on the VSP results, a vertical shaft was sunk at the center of the eastern edge of the target zone. With the exception of a near-horizontal permeable fracture at 20 meters, the shaft encountered very competent grano-diorite to 28 meters. Two major horizontal branches were excavated at the base of the shaft towards the north and south. No tunnel or rubbleized zone was encountered.

Figure 4: *Map view of shaft, tunnel, tunnel-sources (*), geophones, fracture, and 10% of lowest amplitude raypaths from three tunnel sources.*

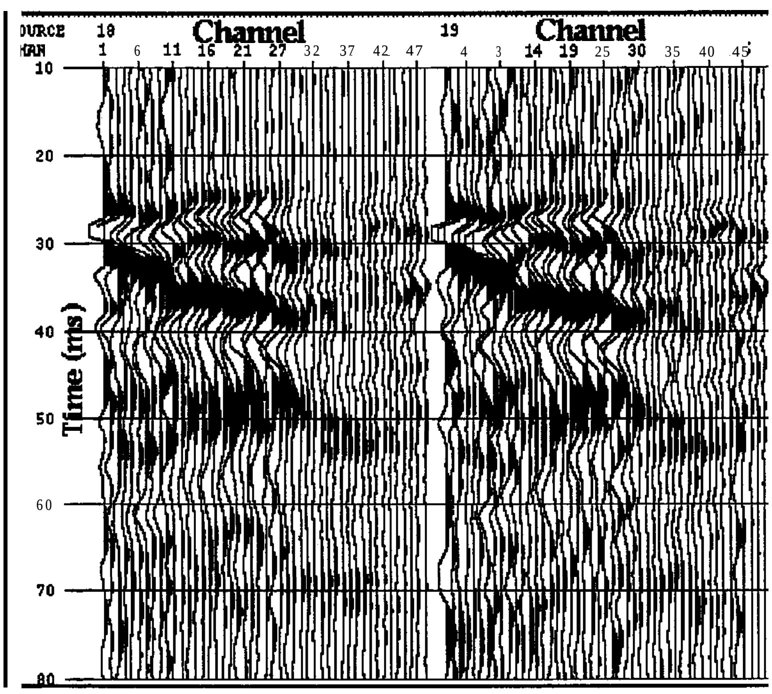
Exploration for treasure-filled tunnels

In February of 1997, excavation was stopped, and we returned to the site to confirm the target and provide final directions for excavation. In the second survey we brought 4840-hertz geophones. We planned an unconventional recording geometry, sources along the walls of the tunnel and geophones at the surface about ten meters west of the tunnel. Figure 4 shows a map view of the shaft and tunnel, as well as the location of the surface geophone line and the sources along the southern branch of the tunnel (shown by the asterisks). Note that the first geophone on the line is at the south end.

In the tunnel-source data from the second survey the anomaly was clearly visible in field records (Figure 5).For sources south of the shaft, the data showed that raypaths to the geophones along the northern end of the line (channels 28-48) experienced significant loss in amplitude. In fact, analysis of data in the field provided sufficient information to direct miners into a 3-5 inch wide near-vertical fracture several meters west of the shaft. Figure 4 also displays the raypaths from three common source gathers. Details of the processing follow, but shown in the figure are the raypaths (assuming straight rays) for the 10 percent lowest amplitude arrivals at the surface geophones-

DATA PROCESSING SEQUENCE AND VISUALIZATION

The data processing sequence was extremely simple. We understand that the most significant effect of transmission through or around a fracture zone is the drop in direct arrival amplitude, thus amplitude is the quality that interests us (Washboume et al, 1994). We have been careful to account for any statistically poorly coupled sources or receivers by applying surface-consistent amplitude corrections. We calculated amplitudes in a narrow window (10 ms.) around the first break and decomposed them into source, receiver, and offset components. This sequence of amplitude decomposition and correction was carried out twice in succession. For the VSP data, an extra step is involved in correcting for amplitude variations where the hydrophone moves have been "stitched" together, by balancing amplitudes in common source ensembles prior to the surface consistent amplitude correction.



Following the statistical corrections, amplitudes were calculated around the breaks a final time and then exported to our in-house visualization and interpretation programs. The 3D rendering is handled by freely available software from the Geometry Center (geom.umn.edu).

Figure 6 and 7 display 3D perspective views of the shaft, tunnel, and fracture. Also shown are raypaths (assuming straight rays) for both VSP and tunnel source data. 5 percent of the lowest amplitudes for all the data ate shown Figure 6 shows the view looking West, and Figure 7 shows the view from above. Notice (Figure 6) that although much of the rays are confined to within the target zone shown in Figure 2, the rays to the south indicate that the fracture may continue south of well 8.

Figure 5: Common *Shot Gathers for two tunnel sources. Receiver channel 1 is at the south end of the line.*

DISCUSSION AND CONCLUSIONS

We were very surprised that a small feature such as a 3-5 inch fluid-filled fracture could create such a large amplitude anomaly in the VSP data. Before intersecting the fracture we were convinced that the zone was several meters across. If the fracture were air-tilled, we would expect significant attenuation. Majer, et. al. (1997) detected very strong attenuation and reflection caused by a single 4 inch air-filled fracture. When the fracture was filled with fluid, however, the effects were much smaller.

While the tunnel excavation did not make us fabulously wealthy, it did prove the viability of surface-to-borehole imaging of shallow voids. Future treasure exploration at this and other sites in the Philippines known to Arch Ford will utilize this technology extensively. Given the need for tunnel detection in military and industrial applications, we are surprised that 3D VSP has not been used before.

Exploration for treasure-filled tunnels

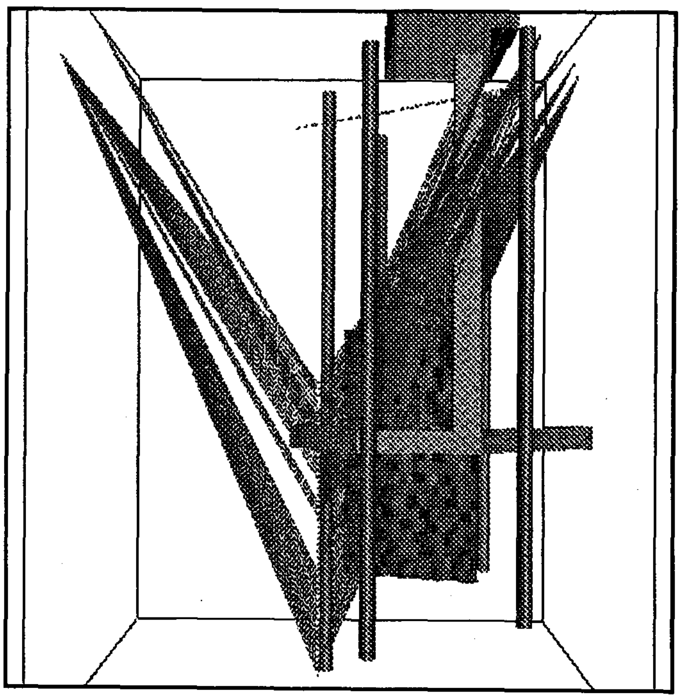


Figure 6: *3D view looking West, showing 5% of lowest amplitudes for VSP and tunnel-source data.*

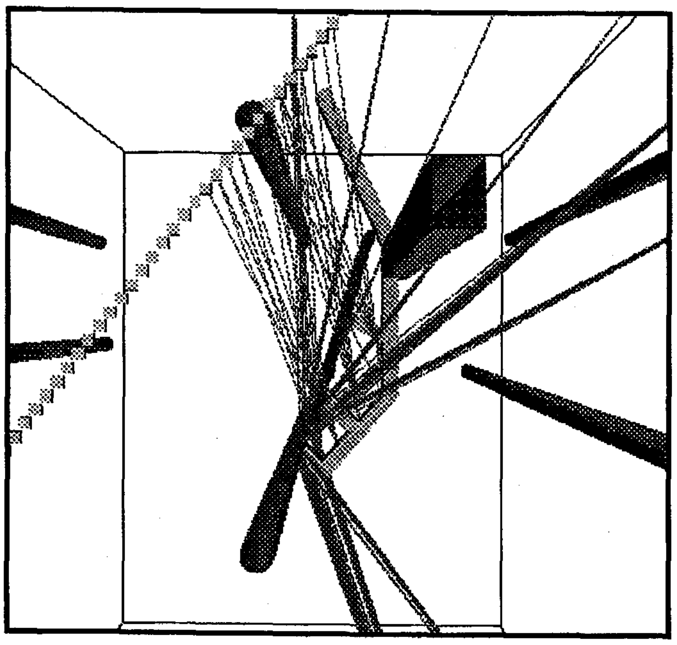


Figure 7: 3D view from above, *showing 5% of lowest amplitudes for VSP and tunnel-source*

ACKNOWLEDGMENTS

The authors would like to thank Arch Ford for the permission to publish this data. We would like to express appreciation for freely available software like **geomview** (available from the Geometry Center; geom.umn.edu) and the **javadevelopmentkit** (available from Sun Microsystems; java.sun.com) that made the computer modeling and 3D visualization for this project possible.

Them is a web site on-line that provides the text and graphics used in this paper in HTML format Also available are MPEG movies of the 3D computer modeling, and the java application used to produce Figures 2 and 4. The java application is a CAD-like GUI that interactively produces the geometry files passed to the 3D renderer. Visit the Tunnel-8 web site:

http://bozo-1.lbl.gov/Tunnel-8/

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